Accelerator technology development at Russia

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Beam cooling

Research using cooling methods opens up wide possibilities for studying nuclear physics and the structure of matter. A large number of unexplored fundamental questions remain in the lower energy area. Many world centers, multifunctional accelerator complexes for the energy of the GeV range are being built or designed, which allow working with both protons and various ions and planning experiments in the field of ion-electron collisions. The most famous of them are projects NICA (Russia), Derica (Russia), FAIR (Germany), HIAF (China) and EIC or even JLEIC (USA). They are created to obtain intense beams of primary and radioactive ions for conducting experiments in the physics of exotic nuclei, nuclear spectroscopy, precision mass measurement, high energy density physics, nuclear reactions in extreme conditions of stellar matter, unique experiments on studying the atomic properties of rare isotopes, studying quarks and gluons inside nuclei, etc. Precision measurements of the masses of rare isotopes carried out at GSI (Germany) and IMP (China) open up wide opportunities for obtaining new information on the structure of nuclei. The USA (RHIC) is developing an electron cooling system based on a linear electron accelerator to increase the luminosity of the RHIC.

At JINR, the construction of the NICA collider with electron cooling systems for a booster up to 60 keV and a main ring with a voltage of up to 2.5 MeV is nearing completion. The low-voltage electron cooler (60 keV) has already been supplied from the INP SB RAS and is ready for cooling the ions. Cooperation with the Mainz University (Germany) is developing in the framework of the development of an electron cooling unit for energy up to 8 MeV (FAIR). In order to expand the possibilities of using electron cooling in experiments in atomic physics, the electron cooling installation at the HIRFL complex (China) modernized. BINP SB RAS can take an active part both in the creation of classical installations for electron cooling based on electrostatic acceleration, and in the development of technologies for high-energy cooling based on ERL.

- Transverse magnetic beam expansion (for higher cooling rate),
- reduction of transverse T_e (improved resolution)
- use of cryogenic cathodes, reduction of longitudinal T_e
- hollow electron beam

Main challenges: high voltage generation; power transmission to high potential; generation of magnetic guiding field.

Fields of interest (in general):

- Development of beam cooling methods: electron and stochastic, combination of both cooling method for beam accumulation with RF barrier bucket system and cascade of RF bunching systems;
- Design and construction of new types of superconducting magnets including HTSC technologies;
- Development of synchrotron power supply systems using HTSC energy storage elements;
- Development of ESIS type ion sources with superconducting solenoid;
- SC resonators for pulsed and cw hadron linear injectors;
- Room-temperature high current cw-RFQ and cw-DTL;
- Technologies for high intensity polarized ion source;
- Precise laser metrology for colliders and ultra-small emittance machines;
- Development of modern automatic control systems with elements of machine learning technologies;
- Development of education programs on the basis of modern technologies.

What R&D would enable these future opportunities?

- **Beam accumulation with bunching and cooling, maintaining a high luminosity level of the experiment at a record low energy and high intensity bunches;**
- Optimization of nonlinear dynamics, dynamic aperture and energy acceptance, collective instabilities, accumulation of electron clouds in a positron beam, etc;
- **HV electron and stochastic beam cooling by fast 3D cooling;**
- **Stochastic beam cooling for ultra-high vacuum collider storage rings, using optic cables and RF antennas;**
- Usage of superferric fast-cycling SC magnets in intense RI beam facilities including e-RI colliders looks promising. Usage of such magnets is useful for hadron therapy synchrotrons and gantry due to their compactness and energy efficiency.
- R&D of compact high gradient (up to 100 T/m) superconducting quadrupole lenses and other final focus magnets.
- R&D of resonators for RFQ and DTL structures designed for operation with high-intensity low β ion beams from low-duty cycle up to cw mode;
- R&D of compact cryo-elements of crab-waist systems placed inside the detector in close proximity to the interaction point;
- Electron String Ion Source (ESIS) for operation at injector for synchrotron (large pulse intensity +high quality beam);
- Technologies for ultra-high precision positioning and monitoring of ring elements (magnets, lenses, BP sensors, etc.);
- Technologies related to the development of magnetic structures with ultra-low emittance;
- Investigation of the photo sorption properties of vacuum surfaces and coatings (NEG)

“Russia Accelerative”: Perspectives of future (+ under construction)

NICA Collider main goals:

to obtain new data on hot and dense baryonic matter: - *is there a first-order phase transition?- is there a critical point?*

nucleon spin structure: *how the spin of proton/neutron is composed*

Project parameters:

- *relativistic ions from* ***p*** *to* ***Au*** *at energies* $\sqrt{S_{NN}}$ = ***4-11*** *GeV,* $L = 10^{27}\ cm^{-2}s^{-1}$
- *polarized* ***p*** *and* ***d*** *up to energy* $\sqrt{S}$ = ***27*** *GeV (p),* $L = 10^{32}\ cm^{-2}s^{-1}$

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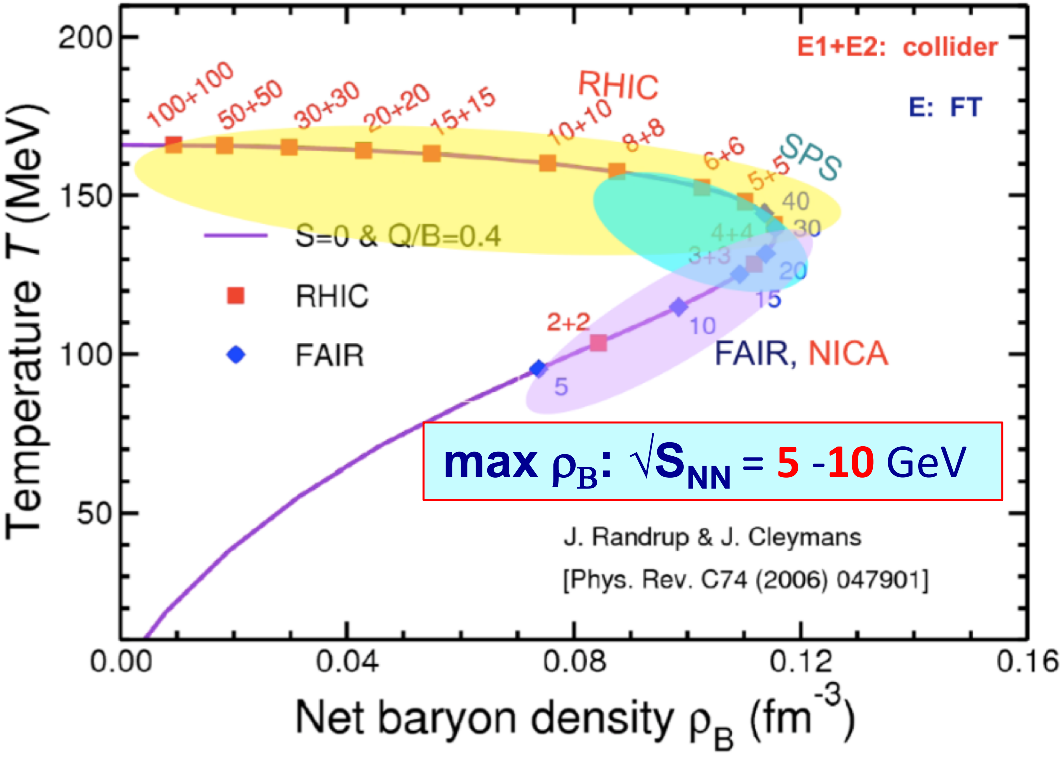
http://nica.jinr.ru/

NICA Collider commissioning - 2022



What new accelerator facilities could be available on the next decade (or next next decade)?

- In the field of relativistic heavy ion nuclear physics and dense baryonic matter – heavy ion collider NICA (an international project) is being constructed at Dubna (JINR). It is planned to start its operation in 2023. The facility uses the unique three-stage of beam accumulation and formation cascade, utilizes three beam cooling systems. The possibility to carry out the precision experiments with polarized p/d beams opens an additional research field of NICA, namely the spin physics.

- In the field of HEP/Particle Physics the Super Charm-Tau Factory is designed and steadily constructed at Novosibirsk (Budker INP): an electron-positron collider with a circumference of 478m, at energy $\sqrt{S}$= 3-7 GeV, with luminosity not lower than 10^{35} $cm^{-2}s^{-1}$. The main experimental program is to study processes with c-quarks and tau-leptons, also operation with a longitudinally polarized electron beam is foreseen.

- In the field of low-energy nuclear physics - the CDR of the DERICA (Dubna Electron – Rare Isotope Collider fAcility) project at JINR is under consideration. RIB facility DERICA concept covers broad range of modern nuclear physics with intense secondary RIB (new isotope synthesis and production, its masses, lifetimes and decay modes, nuclear reactions and spectroscopy). The emphasis of the project is storage ring physics with ultimate aim of electron-RIB scattering studies in collider experiments enabling to determine the fundamental properties of nuclear matter - electromagnetic form factors of exotic nuclei.

- The design of a new accelerator for energies up to 1-5.5 GeV with a beam power of 1.5-2.0 MW and a neutron flux density of 10^{16}n/cm2s is underway at INR RAS (Troitsk).

- Design and construction (after 2025-2030) of MWatt neutron spallation source at IHEP NRC KI (Protvino) is in progress.

- At Budker INP (Novosibirsk) the construction of the Siberian Ring Photon Source (SKIF) has been started in 2019. It is a 4+ generation synchrotron radiation source (476 m ring), 3 GeV beam energy and emittance of up to ~ 50-60 pm. Commissioning of the source is scheduled for 2023. SKIF is intended for research with bright, intense and coherent radiation beams in a wide range of wavelengths from vacuum UV up to hard X-ray.